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Advanced laser heat treatment with respect for the application for Tailored Heat Treated Blanks

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Abstract

Aluminum alloys offer a great potential for lightweight construction. By application of Tailored Heat Treated Blanks (THTB), the feasibility of complex car parts out of aluminum alloys can be enhanced decisively. To extend the process window for forming of aluminum, a large scale area has to be heat treated. Accordingly, this paper deals with the large scale heat treatment via laser radiation. Thereby, a multi-path heating strategy is developed and discussed. In order to get a sharp transition area, different cooling methods and the influence on the heat distribution is qualified as well. In this context, the temperature and hardness are measured.

Keywords: Tailored Heat Treated Blanks; aluminum alloy; laser heat treatment

1. Introduction

Against the background of climate warming, cumulative CO_2 emissions and increasing oil prices, the automotive industry has to face new challenges. With the goal to keep the CO_2 emission targets and hence to reduce fuel consumption of future cars, lightweight construction is a must for the automobile industry [1, 2]. Regarding light weight car body parts, aluminum offers, due to its low density, a great potential for weight reduction. The high specific strength, stiffness and the corrosion resistance as well have promoted a great field of application for aluminum. Comparing to deep drawing steel, like DC 04, the formability of aluminum alloy, however, is low. In order to improve the forming limits of aluminum alloys, several innovative technologies have been invented in the last few years [3, 4]. One of these promising technologies represents the so called Tailored Heat Treated Blanks (THTB), which is investigated in detail at the Chair of Manufacturing Technology at the University of Erlangen-Nuremberg. THTB are locally heat treated blanks with a specific strength distribution adapted to the forming operation, e. g. deep drawing. The application of THTB allows an enhancement of the formability of the blanks with optimized properties resulting in a more robust and shorter process chain for manufacturing of complex car body parts of aluminum.

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2. Principle of Tailored Heat Treated Blanks

2.1. Fast hardenable aluminum alloy

The aluminum alloys mainly used in the automotive industry belong to the 5000- and 6000-series. Alloys of the 5000-series are natural hardened exhibiting magnesium (Mg) as the main alloying element. Since natural hardened alloys show stretcher marks after forming, they are only used for non-visible parts. In contrast, there are alloys of the 6000-series hardened by precipitate formation of the alloying elements (Mg and Si). Being free of stretcher marks after the forming process, they can be used primarily for visible or outboard parts. In order to reduce the recycling costs and to achieve higher scrap prices, the automobile industry favors more and more uni-alloy concepts, respectively alloys of the 6000 series [5]. Alloys of the 6000 series are available in the natural aged T4 condition. In that natural aged T4 condition, the fine precipitates of MgSi clusters interfere with the neighbored particle and deform the optimal strainless lattice structure. Hence the dislocation motion, which is responsible for plastification of the material, is inhibited and the material strength increases. Applying a heat treatment the maximum strength of the material could be gained. By holding the temperature at an elevated level and expanding the heat treatment time the size of the MgSi cluster grows and the material strength increase furthermore. In this artificial aging process the material gains its final strength at the expense of the formability. This artificial aging takes place during the paint bake process at a temperature of 185 °C. With the paint bake lasting in a range between 20 and 30 minutes many fast hardening aluminum alloys have been developed in the last few years [6].

In order to enhance the formability of fast hardenable aluminum alloys, the strength of the material has to be reduced for the forming operation. This is realized by a heat treatment at a high temperature for a very short time. Thereby, the natural aged T4 condition is led back to a condition similar after the quenching. Because of the short heat treatment time a quasi solution heat treated condition is reached. At this condition, the material shows low strength and high formability. The hardening MgSi clusters, which form during the natural aging at RT, dissolve following of the heat input [7, 8]. Providing a decrease of the strength and a higher formability, this effect can be used for the forming of complex parts. With respect to the importance of the heat treatment of fast hardenable aluminum alloys of the 6000-series for the failure free forming, the present work deals with THTB of AA6016PX.

2.2. Enhancement of the process window by THTB

As mentioned before, the fast hardenable aluminum alloys of the 6000-series start to form precipitations of alloyed elements after the quenching. With the goal to enhance the formability of aluminum alloys, the strength first has to be reduced locally. Thereby, the hardening MgSi clusters, which form during the natural aging at RT after quenching, are dissolved by a so called short term heat treatment. This heat treatment method holds a high heat input for a very short time. Applying the short term heat treatment, it is possible to reverse the natural aged condition T4 for a specific period, in which the forming operation takes place. Directly after a short term heat treatment the alloy holds a quasi solution annealed condition, which is characterized by reduced yield strength (YS) and tensile strength (TS). Applied

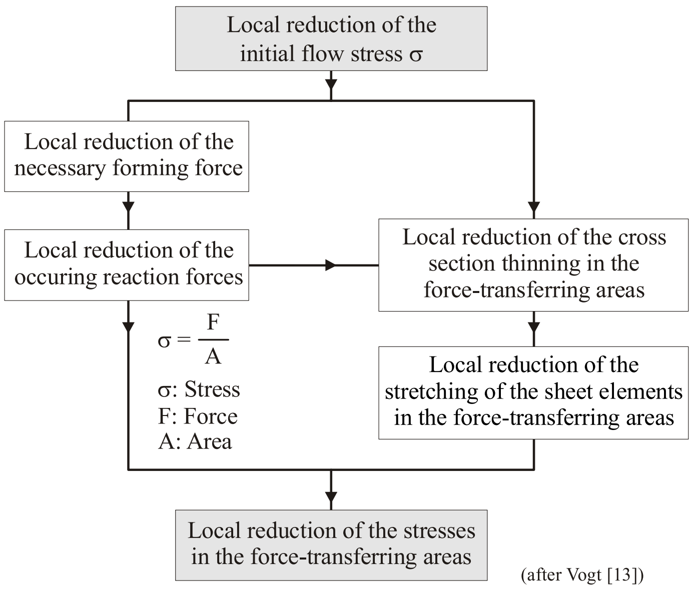

Fig. 1. Active principle of the Tailored Heat Treated Blanks

locally, it is possible to create a blank with specific strength patterns, i. e. the blank poses locally appropriate properties to different forming operations. Therefore, the forming limit can be enhanced [8, 9]. The main approach is based upon the local short term heat treatment to soften those areas on the blank, where the greatest plastification of the blank occurs. Due to local heat impact the initial true stress $\sigma_{t,\,0}$ of the so called forming zones is reduced. As a consequence of the reduced beginning of the plastification, two key mechanisms against failures can be generated (Fig. 1). By reducing the initial true stress, the necessary forming forces decline. Hence, the reaction forces of the material decrease and the load of the forces-translation areas falls. This promotes a faultless forming operation and an increase of the drawing ratio at the same time. An additional contribution enhancing the crack limit is given by the material flow [10]. As a result of the lower true stress, the resistance of the heat treated area of the material drops. For this reason the material flow from the forming zones into force-translation areas is elevated. The local thinning of the blank can be lowered and the occurrence of cracks is strongly reduced. Finally the forming limit is sustainably enhanced [11, 12].

As mentioned above, the blank is softened by the short term heat treatment. With the initial flow stress declining distinctively, the material flow from the forming and heat treated area into the forming zone is effectively facilitated. The stamping forces, required for the plastification of the material, decline as well, which in turn lowers the tangential stress in the forming area. These stresses are responsible for the buckling of the blank out of the sheet plane. In this context the risk of wrinkles, representing a key failure for the deep drawing process, can be minimized effectively and the process window in turn can be enhanced [7, 13]. Since the material shows low formability for certain temperatures, the heat expansion and, above all, the coupled heat transition zone have to be regarded. In this context, the thermal conductivity of aluminum is a challenge for the heat treatment technology and strategy. Therefore, the heat treatment has to fulfill two key demands. The first one is to provide the required heat energy for a homogeneous softening of the blank. The second one is to localize and to limit the heat transition zone between the heat treated and untreated area.

3. Laser heat treatment

3.1. Heat treatment technologies

For manufacturing of THTB the heat treatment is essential. Thereby, technological and economical issues as well have to be considered for the heat treatment strategy and method. With respect to the technological issues, the most important parameters are heating time t_{heat}, holding time t_{hold}, cooling time t_{cool} and maximum temperature T_{max}, as shown in Fig. 2. Due to the high thermal conductivity of aluminum, the boundary of the heat treated area is a challenge for the treatment. Therefore, it is necessary to shorten the heating time t_{heat} in order to localize the heat treatment area. Without excessive cooling methods the strategy needs to feature a high heating gradient $\Delta T / \Delta t$. Another technological issue represents the supply of homogeneous properties of the heat treated areas. As the maximum temperature affects the material strength, the deviation of the temperature depending on different heating strategy and method has to be taken into account. Moreover, the reproducibility of the maximum temperature T_{max} promotes the manufacturing of identical THTB as well. Besides the technological aspects of the heat treatment method and strategy, the economical issues have to be considered. Thereby low investment costs (apparatus and tooling) and low operating cost (short operation time, short setup periods, maintenance expenses etc.) need to be scored. Regarding the technological and the economical requirements, three methods for the heat treatment are identified: laser radiation, electromagnetic induction and heat transfer via cartridge heated steel plates. Electromagnetic induction fails as an appropriate heating technology because of the high costs for design procedures

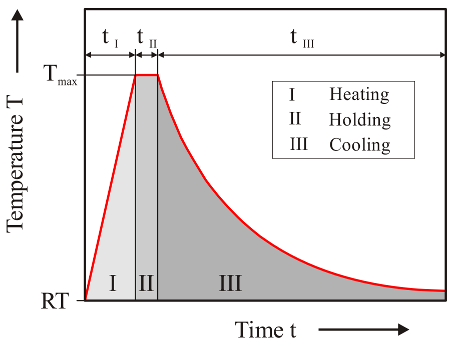

Fig. 2. Schematic temperature - time profile for the heat treatment

for the heating tool and thus engineering costs. As laser radiation has many advantages with respect to the flexibility and heating power, this method is preferred for prototyping, for limited-lot production, and for the laboratory as well. With the heat transfer holding low engineering and tooling cost as well as low setup costs, the heat transfer via cartridge heated steel plates is also suitable for the laboratory.

3.2. Laser beam strategy

Comparing the advantages of laser radiation with those of the heat conduction method, laser radiation is the more suitable for this investigation. Since the laser has a high heating power and flexibility as well, the demands of a localized and limited heating area can be fulfilled best by laser radiation. Regarding typical car body parts, it is clear that large scale areas have to be heat treated. As far as the conventional laser technology is concerned, the heat treatment of a large scale area is realized by adjoining, consecutively paths of the laser spot. Since the laser spot usually covers only a small area, the large scale heat treatment via laser radiation is a challenge to the strategy. In this context, a strategy has to be developed respecting one key demand, the temperature distribution. Thereby, the laser induced heating strategy has to ensure a homogeneous heat input in the heat treated area. Going along with the dissolving of the hardening MgSi precipitates, the softening rate depends on maximum temperature T_{max} [14]. Therefore, the heat input and the heat distribution influence the material properties and, in turn, directly the formability of the THTB.

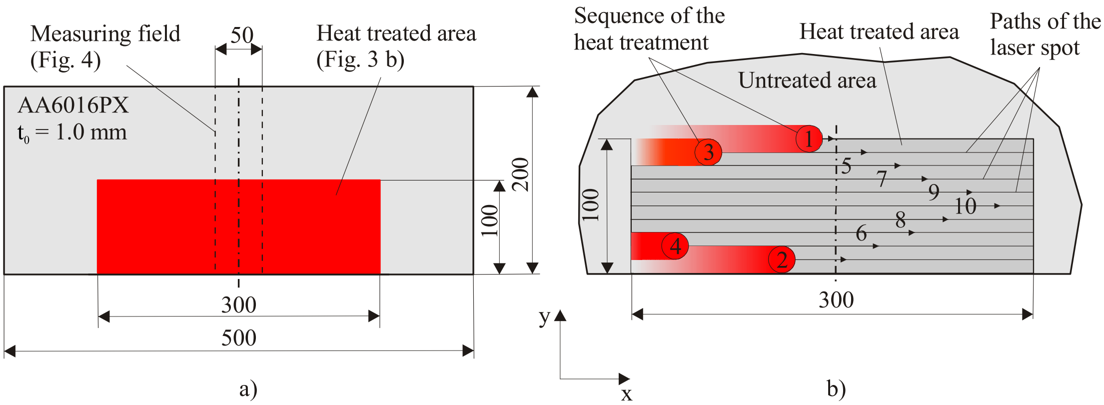

Fig. 3. (a) Tailored Heat Treated Blank with large scale heat treated area and measuring field; (b) Multi-path heating strategy via laser radiation for the large scale heat treatment of the Tailored Heat Treated Blanks

In the framework of this investigation, studies were performed on a rectangular blank dimensions, 500 mm x 200 mm, out of fast hardenable aluminum alloy AA6016PX with a thickness t_0 = 1 mm (Fig. 3a). In order to cover the heat treatment layout of 300 mm x 100 mm homogeneously the laser spot was driven consecutively along ten adjoining paths. Illustrated in Fig. 3 b, these paths, with a length of 300 mm in x - direction and y - shift of 10 mm, are parallel to each other. As the laser spot has a diameter of 20 mm, the area between two adjoining paths is exactly irradiated twice. Thus, it can be assured that the heat treated area gained the required heat energy to dissolve the precipitated MgSi cluster. Furthermore, a pause during two consecutive heating cycles was integrated. Lasting for t = 30 s this pause gives the heated blank enough time to cool down via self quenching. With respect of the process time, the heat distribution and the required cooling time, the sequence of the heat treatment was optimized so far, that successive paths held the biggest distance to each other (Fig. 3 b). By applying the pause for cooling between the heating sequences, a blank condition similar to the initial blank could be provided before each heating cycle.

As far as the laser heat treatment technology is concerned, four parameters were essential for the temperature progression and extension via radiation. Regarding the optical and laser parameters, the wavelength of the radiation λ, the spot diameter d_L and the laser power P_L have to be taken into account. The controlling parameter is represented by the speed of the robot v_L, guiding and leading the fiber optics, in which the radiation is coupled into. With aluminum showing a high absorption rate for the infrared emission, a neodymium-doped (Nd:YAG) solid-state laser with a wavelength $\lambda = 1064$ nm was applied as radiation source. Since the heat input depends on the laser spot and the laser power, the spot size was held for the whole study constant at 20 mm without varying the laser power ($P_L = 2400$ W of maximum available 4000 W). Additional to the sequence of the heating strategy and the pause of 30 s between two successive heating cycles, the speed v_L of the robot guided laser was varied, optimizing a homogeneous temperature distribution. In this context, the speed v_L ranged between 25 mm/s and 29 mm/s. Depending on the temperature distribution and the distance to the previous path, the speed for the running heating cycle was adjusted, aiming for the same maximum temperature. In conclusion, through the timely and locally decoupled character of the laser-induced heat treatment, by applying the multi-path heating a quasi-homogeneous temperature distribution over a large scale area of a THTB was realized.

3.3. Characterization of the material properties

The multi-path heat treatment introduced above presents a good approach for large scale heat treatment of THTB. Applying the multiple laser radiation and the heating strategy, a quasi homogeneous temperature distribution can be achieved. On the THTB blank two properties plateaus arise. On the one hand there is the softened one in the heat treated area. On the other hand there is the precipitation hardenable one of the initial blank. Since the material properties change in the transition zone due to the temperature gradient, it is quite important to investigate the influence of the transition zone on the forming process as well. This transition zone and, above all, the heat extension of the laser radiation were characterized by temperature and hardness measurements. For this purpose a field of 200 mm x 50 mm was taken out of the heat treated area (Fig. 3 a, Fig. 4). By using thermal elements, which are soldered along the symmetric line of the THTB blank, the temperature was measured every $\Delta y = 10$ mm. As far as the transition zone is concerned, the distance between two consecutive points was reduced to $\Delta y = 5$ mm. The goal here is to get more detailed information about the heat transfer and its influence on the material properties. Since the laser radiation did not allow a simultaneous heat input of a large scale area, each measuring point showed a temperature peak during the heat treating process. The amplitude of this peak depends on the distance to the heating path and traced back to the high thermal conduction of aluminum. With increasing distance to the heating path, this peak declined and nearly vanished in the untreated zone. The maximum temperature T_{max}, however, was only scored at the measuring point located directly in the middle of the path irradiated by the laser radiation. Again, the distance between the points 10 to 16 is reduced to $\Delta y = 5$ mm (Fig. 4).

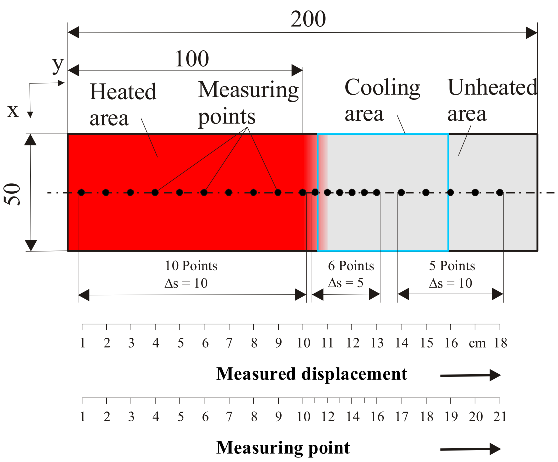

Fig. 4. Measuring field taken from the middle of the heat treated blank of AA6016PX with measuring points

As far as the multi-path heat treatment strategy and respectively the multiple irradiations of the blank are concerned, unwanted effects may occur. These could hinder a defined adjustment of the material properties. As mentioned above, the area between two adjoining paths is irradiated twice. Additionally, this area is heated by thermal conduction of the aluminum blank as well. The multiple heat input can elevate the material strength by facilitating and accelerating the forming of the hardening MgSi - precipitates like during the bake hardening process mentioned in 2.1. For the local softening of the THTB, however, it is essential to avoid this mechanism. Therefore, a hardness measurement across the heat treated and untreated area is necessary for two reasons; on the one hand to characterize the crossing area between the heated zone and the untreated blank; on the other hand to assure the softening of the material in the heat treated area. As far as the measurement was concerned, a field of 200 mm x 50 mm was cut out the blank after the heat treatment and tested. As a standardized testing method the

Brinell hardness test was applied according to DIN EN ISO 6506. The measuring points for the hardness values were set at the same position as those for the temperature measurement.

Providing the reproducibility of identical THTB, the heat expansion over the entire blank had to be characterized in detail. The intensity distribution of the laser radiation, the large scale heat treatment and the fast heat conduction of the aluminum were challenges for the heating strategy. Finally, a multi-path heat treatment strategy was developed allowing a quasi homogeneous heat input. Regarding the temperature gradient between the heat treated and untreated area, the transition zone has to be focused. Since this transition zone is critical for the forming, the next section deals with the localization and limitation of this heat transferring zone and its influence on the material properties. Furthermore, in order to minimize this transition and heat transferring zone, alternative cooling technologies are investigated and qualified by hardness measurement.

4. Impact of the multi-path heat treatment strategy

4.1. Influence of the cooling methods on the mechanical properties

Additional to the technological parameters coupled with laser radiation, the strategy of the multi-path heat treatment has an essential influence on the material properties. Due to high heating rate for a very short time via laser radiation, the softening of the material is not enduring. Moreover, the heat induced local softening of the material is temporal limited. According to [8] it can be assured that the material strength does not change significantly within one hour after a short term heat treatment. In order to characterize the softening potential of a short term heat treatment, the hardness was identified as a representative parameter for the material strength. Since the time and effort for the Brinell hardness measurement could be realized within few minutes, the heat treated blank was tested according to DIN EN ISO 6506. As shown in Fig. 5 a) the impact of the laser heat treatment on the THTB blank is illustrated by means of the temperature and hardness. Clearly, a quasi homogeneous temperature distribution could be achieved for the large scale heat treated area. Regarding the temperature curve, two effects are significant.

The first one is related to the temperature declining more than 150 °C between the measuring points 10 to 11. Since this gradient was settled in the heat treated area, the heat input of the laser and the multi-path heating strategy have to be addressed in this context. Besides the Gaussian distribution of the laser intensity and the laser energy, the key reason lies in the heating strategy. Since the first heat treated path was realized at the measuring point 10, the blank was still cold before the heat treatment. This area was not heat treated via thermal conduction before. Inducing the constant energy of 2400 W, the heat was conducted immediately over the large scale blank. Therefore, this area could not reach the same temperature level as consecutive paths.

The second one was gained in the heat treated area. As mentioned above, the blank was heated several times. The heat was induced directly the via laser radiation on the one hand, and indirectly via thermal conduction on the other hand. Since the paths between the points 4 to 8, settling in the middle of the heat treated area, is heat treated last – regarding the succession of the laser radiation (3.2) – this area get a larger heat input. As a consequence, the temperature increases here (Fig. 5 a).

Regarding the mechanical properties presented by the hardness distribution, the multi-path strategy is a good approach for a homogeneous heat treatment of a large scale area. Compared to the temperature gradient between the heat treated and untreated area, the hardness shows the expected behavior. As mentioned in Fig. 4, the distance of the measuring points 10 to 16 was shortened to $\Delta y = 5$ mm to get a higher resolution of the transfer zone. Exactly at the border of the large scale heat treated area, the hardness increases from the softened level of less than 50 HBW at point 10 to the elevated level of the initial blank of 73 HBW at point 11. This jump of the hardness is led back to the heat input. Despite the low temperature characteristic between the points 11 to 12, the induced heat, which is required to solve the hardening precipitates of the aluminum alloy, was gained at the first heating cycle. In the heat treated area, however, respectively between the points 4 to 9 the hardness seems to have an inconsistent characteristic (Fig. 5 a). As mentioned above, the temperature in the middle of the heat treated area is higher due to the consecutive heating strategy (3.2). Expecting the temperature being higher the middle of the heat treated zone between the points 4 and 8, the hardness supposed to fall as a consequence. However, the hardness characteristics show a different manner at the point 5. A closer look at the multi-path heating strategy identifies the driving reason.

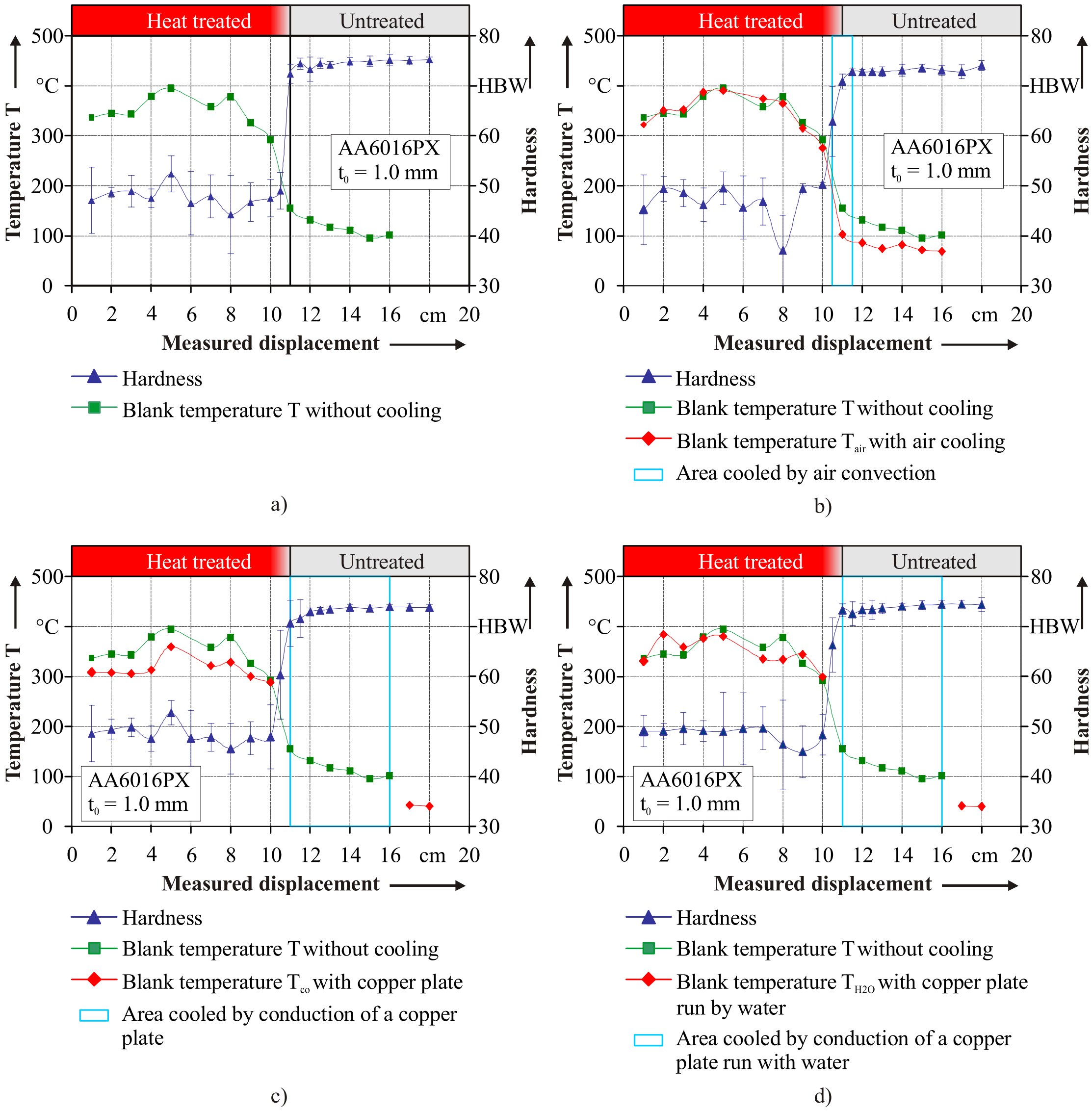

Fig. 5. Influence of the cooling method on THTB; (a) cooled without medium via self quenching; (b) cooling via air convection; (c) cooling via thermal conduction of a copper plate; (d) cooling via thermal conduction of a copper plate run with water

Each laser heat treatment is coupled with the thermo-mechanical effects. Due to the multiple heat treatment strategy the blank temperature increases and declines after each heating step. Since the material expands locally with the increasing temperature and as the surrounded blank area does not expand, compression stresses occur in the heat treated area. During the cooling step, where the temperature falls, the blank contracts. Going along with this effect, tensile stresses arise due to the resistance of the untreated area. Since the strength in the untreated area is higher than in the heat treated, a homogenous contraction of the blank is hindered. The cycle between expansion and contraction, and, above all, between compression and tensile stresses elevates the residual stress of the blank after cooling down. With growing number of the heating steps the residual stresses increase as well. Due to the heating strategy the middle of the heat treated area is heated last. Therefore, the additional increase of the residual stresses is expected to be maximal in the middle of the heat treated area. As a consequence, the strength of the material increases locally (Fig. 5 a).

An additional mechanism accompanying the thermo-mechanical effects is the buckling of the sheet blank. This effect is supported by two effects coupled with the multi-path heat treatment. The first one is the softened blank area holding a lowered initial flow stress after the heat treatment. The second is the continuous increase of the residual stresses going along with each heating and cooling cycle. If the thermal induced compression and tensile stresses exceed the yield strength, the material starts to flow. This process is coupled with reduction of the operating stresses by lasting deformation. As the deformation of the heat treated area is hindered by the surrounded area, the blank is plasticized by buckling out of the sheet plane, forming wrinkling. In this context, the hardness characteristic in the heat treated area shows a wavelike curve from the points 1 to 9 (Fig. 5 a).

As mentioned before, the heat expansion from the heat treated area into the untreated area is quite fast. Due to the high thermal conductivity of aluminum these areas may get enough heat energy sufficient for local softening. Therefore, three cooling methods are applied. Besides the self quenching via air convection at the atmosphere pressure of $p_0 = 1$ bar, the heat was conducted at an elevated pressure of $p = 8$ bar with air as cooling medium. Thereby, the air ran through a pipe with a drill hole of 2 mm diameter each 10 mm. The second method to localize and to limit the heat expansion into the untreated area was realized by the thermal conduction of a copper plate. In order to enhance the cooling rate and the heat removal, this copper plate is additionally run with water. The influence of these three cooling methods on the mechanical properties, represented by the hardness, is illustrated in Fig. 5 b – d.

As expected, the heat removal of the three cooling methods via air convection and thermal conduction via the copper plate with and without water was clearly enhanced in the untreated area. Providing a temperature difference $\Delta T = 200$ °C in the transition zone between the points 9 to 11, the cooling rate via air convection is about 15 % higher than this without cooling via self quenching. The same results could be achieved for the thermal conduction via copper with and without water. In both cases the temperature declined more than 200 °C and the cooling rate increased about 67 % compared to the rate without enhanced heat removal. Since the copper plate hinders direct measurement, the temperature was taken at the points 10 and 17 (Fig. 5 c-d). Considering the homogeneous temperature characteristics of the air convection, the same effects can be suspected for thermal conduction via copper. The hardness characteristic in the untreated area, showing a homogeneous distribution, attests this assumption (Fig. 5 b-d).

As far as the hardness distribution of the cooling methods is concerned, no significant influence of the enhanced heat removal was gained. Focusing on the untreated area, the hardness shows a similar characteristic with and without additional cooling. In this context, an average hardness of 74 HBW and a variance less than 3 % was achieved. Despite the temperature drop in the untreated area, the attained hardness remains nearly unchanged providing a similar level to the initial blank. The reason for this effect lies in the induced heat input needed to solve the MgSi precipitates. Without additional cooling the untreated area is heated up more by thermal conduction. The elevated impact of the induced heat energy, however, does not suffice to initiate the dissolution of the precipitated MgSi cluster exhaustively. Since the blank keeps a similar proportion of the hardening precipitates, no macroscopic difference of the hardness is detected. Concerning the heat treated area, the hardness is mainly influenced by the maximum temperature T_{max} and the heat treatment strategy. Since both parameters do not change and the hardness characteristics show a similar trend, the influence of the additional heat removal via air convection or thermal conduction has no effect for the heat treated area. The deviation of the average hardness traces back to the thermo-mechanical effect. As shown above, the periodic heating cycles affect and enhance the residual stresses resulting in buckling of the blank.

4.2. Influence of the cooling methods on the transition zone

As mentioned above, the transition zone, located between the heat treated and untreated area, is quite important for the forming of THTB. Since the temperature declines, the material properties change as well. Providing low formability, this transition zone may hold an elevated risk of failure [15]. With the goal to expand the forming limit and to enhance the formability of THTB, this zone has to be reduced. In this context, a sharp transition between heat treated and untreated area is required. Therefore, it is necessary to limit the heat expansion from the heat treated into the untreated area. Against the background of restriction of the heat in the untreated area, the cooling methods, shown in 4.1, were applied. Besides the temperature characteristic the mechanical properties, here represented by the hardness, have to be considered in detail.

Illustrated in Fig. 6, the hardness characteristic of the transition zone for the investigated cooling methods is shown. Focusing the heat transition zone between the points 9 to 14, which extend to 30 mm, the hardness characteristic, however, shows an unexpected behavior. Although the hardness difference between heat treated and untreated area is nearly constant, the heat transition zone of the cooling method via self quenching is clearly smaller than those via air convection or thermal conduction. Holding a range of 5 mm between the measuring points 11 and 12, the heat transition zone cooled via self quenching is about 50 % smaller than that cooled by air convection.
The reason is found in the cooling method itself. In order to gain a sharp heat transfer zone and a local heat treated area, the cooling method was set at the border of the heating zone. Thereby, the heat expansion into the untreated area was reduced significantly (Fig. 5). Due to the position of the cooled area, however, the heat, furthermore, was in the heat treated area. Since the heat input is required for dissolving the precipitation and thereby softening of the material, the hardness increases as a consequence. This effect is shown at the point 11. The average hardness of the cooling method is about 10 HBW higher than this cooled via self quenching.

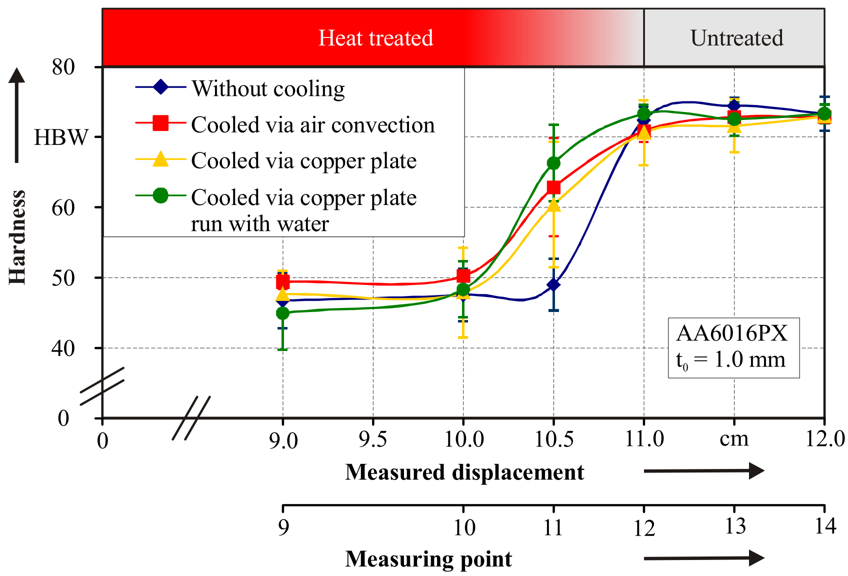

Fig. 6. Influence of different cooling rates on the heat transition area of a THTB

In conclusion, the multi-path heat treatment allows a quasi-homogeneous heat treatment for the THTB. Depending on the timely and locally decoupled strategy of the multi-path heat treatment, thermo-mechanical mechanisms occur, which influence the temperature and hardness characteristics and distribution of the THTB. With respect to minimizing the heat transition zone, three cooling methods were investigated. The best result was achieved via self quenching without any additional cooling. In this context, a heat transition zone of 5 mm was obtained.

5. Conclusions

THTB are locally heat treated blanks with a specific optimized strength distribution adapted to the forming process. Holding many advantages especially under research conditions, laser radiation was elected as the technological heating method. In this context, heat treatment of blanks (500 mm x 200 mm) of the automotive aluminum alloy AA6016PX with a thickness of 1 mm was investigated. In order to improve the formability of car body parts, a large scale area on the blank has to be heat treated. In order to gain a homogenous heating of a large scale area via laser radiation, a multi-path heat treatment was implemented. Regarding the temperature and hardness distribution, the required softening was realized well. Due to the laser radiation, which is coupled via the laser forming mechanisms, wrinkles occur in the heat treated zone, which, however, deform the plane blank. With respect to reducing the heat transfer via thermal conduction of aluminum and to minimize the heat transition zone, three different cooling methods were applied – air convection, thermal conduction via a copper plate with and without water. It was shown that the heat could be clearly conducted best via thermal conduction. The heat transfer into the untreated area was limited significantly regarding the temperature characteristic. Expecting a sharp gradient of the mechanical properties by applying the additional cooling methods, the hardness, however, shows a different characteristic. To this, the heat is conducted in the untreated and heat treated area as well. Therefore, the softened level near the cooling zone is small, which results in an enhanced hardness level. Thus, the sharpest translation area is gained without any additional cooling via self quenching.

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